To: National Aeronautics and Space Administration
Washington, D. C.
Attn: Mr. Henry Burlage

From: Dr. B. A. Reese, Director
Jet Propulsion Center
Purdue University
Lafayette, Indiana

Subject: Semi-Annual Report for Period of
July 1, to December 31, 1965

NsG 592

The work accomplished during the last six month period on this contract is covered under the following task headings.

Task 1. INVESTIGATION OF HIGH PRESSURE COMBUSTION PHENOMENA

Task 2. INVESTIGATION OF SOLID PROPELLANT COMBUSTION

Task 3. ATTENUATION OF TRANSVERSE COMBUSTION PRESSURE OSCILLATIONS

Task 4. SOLID PROPELLANT IGNITION STUDIES

Task 5. SECONDARY INJECTION OF A GAS INTO A SUPERSONIC STREAM

[redacted]

Task 1. INVESTIGATION OF HIGH PRESSURE COMBUSTION PHENOMENA

I. Introduction

Effort by participating personnel during the last quarter of the semi-annual report period has been concentrated on design and analysis in the following research areas--development of rocket test calibration and data reduction procedures, injector design and performance characteristics of high pressure rocket engines, performance and stability characteristics of staged combustion engine systems, and the application of film and transpiration cooling techniques to high pressure engine designs. The procurement of the components for the mechanical system and associated subsystems for the Combustion Research Laboratory is progressing. The evaluation of the design proposals for the data acquisition and facility control systems has been completed and the contract let. Installation of these systems has been initiated.

II. Status of Work in Progress

A. Laboratory

The construction and installation status of the Combustion Research Laboratory for the last report period is given as follows:

1. Buildings

The two bay test cell building, the control building, and four propellant storage buildings have been completed.

2. Mechanical System

All components of the gaseous nitrogen storage, propellant supply, and coolant supply systems have been ordered and approximately 70% of these components have been delivered to the Jet Propulsion Center site.

[redacted]

The drawings for the piping system have been finalized and resubmitted to the contractors for review. Of the three contractors who quoted on the piping system earlier, one declined to rebid, one priced over the budget, and investigation of the third indicated a serious question as to his ability to perform the task. The drawings were then resubmitted to fourteen additional contractors and their proposals are expected during the next report period.

3. Laboratory Instrumentation

The data acquisition system for the Combustion Research Laboratory was completely specified last August. Final proposals from the six bidders were evaluated by the Jet Propulsion Center, Purdue University, with technical assistance from NASA (Mr. Frank Friswold, Lewis Research Center). Honeywell, Inc. from Indianapolis, Indiana was awarded the control and data acquisition system contract early in September. The Electronic Engineering Company of California (EECo) is the digital system subcontractor for Honeywell.

Upon receiving the contract award, Honeywell initiated a series of meetings with the Jet Propulsion Center to discuss specific design details. Discussions were held between EECo, Honeywell and the Jet Propulsion Center to prepare the University Computer Sciences Department for processing the digital data tapes.

The data acquisition system contract specifies the following major components:

1. Analog System

(a) A 7 channel Honeywell model LAR 7400 analog tape recorder capable of recording signals from DC to 20,000 cps is included

(b) A 36 channel Honeywell model 1612 oscillograph includes signal conditioning equipment for 24 channels.

(c) Nine Honeywell model 16K strip chart recorders are also included in the analog system.

2. Digital system

(a) Included is an EECo 765 multiplexer which is a standard of "off the shelf" products, however, some modifications were necessary in order to meet the Purdue specifications. The available sampling rates are: 100, 200, 500, 1000, 2000, and 4000 samples per second. The Purdue specifications requested the ability to hold the multiplexer on one channel for a period of time so that amplifiers could be adjusted during calibration while observing the digital readout; EECo found it possible to provide one additional mode of operation that permits continuous sampling of any single channel by merely setting the channel on multiplexer thumbwheel switches and selecting the proper mode of operation, without altering the multiplexer patch board.

(b) The system also includes an EECo analog to digital converter with a voltage accuracy of 0.01% to 0.015%. The A to D converter must compare voltage levels in order to digitize the analog signals, therefore, it must be the most accurate device in the system. The A to D converter provides a four decimal digit nixie tube display of the contents of any selected channel.

(c) The format generator and buffer unit controls the placement of I.D., time, and data on the magnetic tape. Three thumbwheel switches are provided for the purpose of setting the record length. I.D. data is placed on tape by first setting the three record length switches. I.D. characters can be entered on the tape by means of 12 thumbwheel switches; for example, it would take 4 settings of the thumbwheel switches to dial in 48 characters.

(d) A time code generator and reader unit represents a very efficient solution to the problem of correlating time among several different recording devices. The EECo 858A is one of the few units that is able to generate time signals and read time data from tape recordings. The time code generator produces two basic types of data. One is a "slow" code that can be used to drive the event pen of a strip chart recorder or oscillograph. There is an option to record either one pulse every 5, 10, or 60 seconds. The "fast" code generates time data every second and distributes the signal in parallel to the digital system, analog tape system, and time code generator nixie tube display. The fast code signal is composed of hours, minutes, and seconds (maximum value output is: 23: 59: 59).

(e) The digital tape recorder is a Potter MT 36. It is compatible with an IBM 729 tape reader, and a sample tape generated by the Purdue EECo system has been successfully read by the University Computer Science Center.

EECo performed an acceptance test of the complete digital system on February 1, 1966 with a representative from Honeywell present as a witness. The system checked out satisfactorily and a copy of the completed acceptance test forms are on file at the Jet Propulsion Center. Another acceptance test will be performed when the complete system is on site at at the JPC.

III. Plans for Future Research

A. Development of Rocket Test Calibration and Data Reduction Procedures

Preliminary steps are being taken to write computer programs which will be used with the data acquisition system once it is installed. At present several curve fitting subroutines have been investigated for handling calibrations and found to be very useful for interpolating between data points. Also completed is a program that casts out data points which appear to be in error and generates a linear equation for the given set of experimental points the slope of which will be utilized for a calibration factor.

Two basic types of digital coding are used with the EECo system. BCD code (Binary Coded Decimal) is employed for identification numbers and time words. Experimental data is recorded in pure binary code. There is very little difference between these two types of codes, however, it is more economical to use BCD for I.D. and time words while binary is more economical for experimental data.

Data tape format consists of one or more blocks of identification data which is dialed in by means of thumbwheel switches or the format generator unit. Preliminary studies indicate that blocks of 20, 6 digit numbers appears to be a reasonable record length. The 20 number block can be repeated as many times as desired; each time an I.D. block is repeated the same subroutine can be used to process the identification data.

Calibration tapes, in addition to the identification label blocks described above, consist of a BCD identification block to specify pertinent characteristics of the sensing devices being calibrated, followed by calibration data records in binary code.

Experimental data tapes begin with a BCD identification label record. Data blocks begin with a 6 character BCD time word, followed by binary experimental data. Block length limitations are specified in a chart provided by EECo. The programs are being written to process an arbitrary block length, therefore, the system will be as flexible as possible.

Future projects concerning the digital system include completing the programs necessary to read data tapes and store data in the computer so that it can be located for processing. Once data is stored in accessible locations, programs which process the raw data, print data in engineering units, and write engineering data on tape for input to a fortran program can be combined into one package. A programming manual for the data system will be written in order to provide the Jet Propulsion Center with the information necessary to alter the programs should changes or expansion of the digital system become necessary.

B. Heat Transfer and Performance Characteristics of High Pressure Rocket Engines

The design of a family of cooled research liquid rocket thrust chambers will be finalized within the next few weeks. The motors will be employed to study the effects of high combustion pressure (2000 psia to 5000 psia) upon combustion stability, performance and heat transfer obtained with different types of injectors. The chambers are designed such that they will be cooled regeneratively up to and including a combustion pressure of 3000 psia. Above 3000 psia combined film and regeneration cooling will be used. The nozzles will be converging only and will be film cooled at all pressures.

The design of the injectors is practically complete. They have been designed to produce stable fully turbulent streams so that experimental results will be reproducible from run to run. The resultant momentum of the impinging streams is directed in the axial direction. The injector faces are transpiration cooled utilizing Regimesh.

C. Performance and Combustion Characteristics of a Staged Combustion System

During the past report period two gas generator chambers, two gas generator nozzles, and a gas generator injector assembly were fabricated. A thrust stand is now being built and should be completed within three weeks. An afterburner to burn off the oxidizer rich exhaust products has been designed and will also be built during the early part of the next report period.

A film-cooled Z_rO_2 coated stainless steel thrust chamber will be used throughout the staged combustion system program. Both the performance of the staged combustion system and the effectiveness of film cooling will be evaluated. Fabrication of both the thrust chamber and selected thrust chamber injectors should begin by April 1, 1966.

Testing of the gas generator should begin June 1, 1966, upon the completion of the combustion research laboratory. Evaluation through experimental firings of the staged combustion system is scheduled to begin by August 1, 1966.

D. Feasibility Study of Transpiration Cooling

In view of the high heat fluxes which are encountered in the high pressure rocket engines, a thorough review of the literature pertaining to transpiration cooling was deemed necessary as it represents one of the more promising solutions to the problem. Literature in the following subject areas has been reviewed in detail:

(1) the properties of porous materials

(2) single and two-phase flow through porous materials

(3) a comprehensive evaluation and comparison of the pertinent theoretical and experimental work relevant to mass transfer cooling of a turbulent boundary layer

(4) conclusions regarding the problem areas that have been solved with particular consideration to the potential application of transpiration cooling

The properties of porous materials of greatest interest were strength, permeability, and also porosity which relates to the first two. The commercially available materials were studied in light of the most desirable characteristics and all were found lacking to some degree. The most promising candidates were: (1) sintered metals; (2) perforated sheet; and (3) woven wire cloth. At the present state of material technology, the woven wire cloth possesses a distinct advantage over others in uniformity of permeability and strength. "Regimesh" and "Poroloy" are two examples of this material.

The literature pertaining to single and two-phase flow through porous materials was investigated to ascertain equations that enable adequate predictions of flow rates with a minimum of experimental data. Green's solution, which can be generalized to be applicable for liquids or gases, appears most promising. However, the quantitative prediction of fluid flow through porous media is not always possible when two phases are present. Because of the erratic and reduced flow rates that result from gas entrainment, very few experimental investigations have been conducted to evaluate the effectiveness of a liquid as a coolant.

A major portion of the literature review was devoted to a study of the theoretical and experimental work pertaining to mass injection into a turbulent boundary layer. Rubesin's analysis for air injection and Rebesin and Pappas' extension of that analysis to light gas injection were found typical of existing analyses and as accurate as any other; a unique approach offered by Spalding is easier to apply but more empirical. The experimental work was reviewed from the standpoint of comparing the range of parameters measured by different investigators, the coolants used, the objectives of the tests and the agreement with theory. Emphasis in the forthcoming report shall be not only on the work which has been done, but the existant problem areas which require more attention.

An extensive bibliography has been collected and studied in detail. The report presenting the results of the literature review is in its final stages of preparation and will be completed by June 1966.

(Research Assistants working on this task are as follows: Robert Strickler, Nick Barsic, Lynn Carstens, and John Kelley.)

Task 2. INVESTIGATION OF SOLID PROPELLANT COMBUSTION

I. Introduction

The objective of the research program in solid propellant combustion is to develop experimental techniques capable of yielding information pertaining to the combustion processes of composite propellants. Current programs are concerned with two aspects of the thermal environment of the combustion zone: (a) the temperature profile of the flame above the propellant surface, and (b) the surface temperature of AP (ammonium perchlorate). The surface temperature measurement program was initiated through support of the Thiokol Chemical Corporation and was supported for twelve months by The National Science Foundation.

A modified line reversal pyrometer technique is being employed to make the temperature profile measurements. This technique requires the use of specially prepared composite propellant strands containing alkali metals which serve as temperature indicators. The surface temperature will be obtained by measuring the infrared emission from the burning surface. Pressed strands of pure AP and also of AP plus 10% paraformaldehyde fuel have been obtained for this study. The AP/fuel mixture will enable studies to be made at combustion pressures below the low pressure limit of pure AP. Both programs utilize similar combustion bombs and pressurization systems and unique servo-controlled propellant feedshafts to maintain the burning surface at a known position.

II. Status of Work in Progress

A. Temperature Profile Study

1. Propellant Strand Preparation

The preparation of propellant strands for the temperature measurement experiment is being performed at JPL, Pasadena, California. The requirements for the propellant strands are as follows:

a) The propellant must have a fine unimodal oxidizer grind ($\bar{D}=10\mu$) in order to reduce the surface roughness of the propellant surface to a minimum.

b) The propellant strand must have a thin sheet of propellant in its center which is salted with an alkali metal.

c) The burning characteristics of the propellant must be acceptable over a wide range of pressures (atmospheric to 1500 psia).

Several types of propellants have been tested to date with a unimodal fine grind of ammonium perchlorate as the oxidizer. The following is a list of these propellants types and the pressures over which the propellants have burned satisfactorily.

a) PU - AP (no combustion)

b) PBAA/MAPO - AP (atmospheric to 50 psia)

c) PBAA/MAPO - AP and 1.0% $SrCl_2$ (no combustion)

d) PBAA/MAPO - AP and 1.0%LiCl (no combustion)

e) PBAA/EPON 828 - AP (atmospheric to 250 psia)

The technique of casting a thin sheet of salted propellant in the strand center has been developed. The procedure consists of three separate casting, curing, and machining operations on the propellants.

2. Combustion Bomb System

The combustion bomb system has been relocated in a new test cell. This new location allows more space for the experimental equipment and allows the output from the photomultiplier tubes to be recorded on a 12 channel Ampex tape recorder rather than on a Hathaway oscillograph as originally planned.

3. Servo-controlled Propellant Feedshaft

A new feedshaft drive mechanism has been designed and fabricated. Modifications to the design have eliminated the gear alignment problems which were present in the initial design. The system has been assembled and aligned and is ready for checkout.

B. Surface Temperature Study

1. Infrared Detection System

The infrared detection system has been assembled and mounted. The system includes a reference blockbody source, an infrared monochromator (Perkins-Elmer Model 99), and exterior optics for focusing either the blackbody or propellant emission onto the monochromator entrance slit. Alignment and calibration of the system has been completed.

2. System Integration

Provision has been made to obtain simultaneous measurements of the strand burning rate and the emission from either the burning surface of the strand or the flame above the strand. Suitable mounts and adaptors have been constructed to permit mounting the portable feedshaft mechanism to drive the strand either in, or normal to, the plane of the infrared detection system. A control system for sequentially operating the ignition circuit, servo-controls, and infrared detection system has also been completed and checked out.

3. Preliminary Experiments

Preliminary experiments on igniting strands of AP plus 10% paraformalelehyde at atmospheric pressure showed that irregular burning and flaking of the surface would lead to erratic operation of the servo feed mechanism. A gaseous fuel supply system was then incorporated into the purge system. It was found that certain mixture ratios of a hydrogen-nitrogen mixture flowing along the strand would maintain a plane surface and permit satisfactory operation of the servo system. However, repeated trials showed that the mixture ratio was very critical and that surface burning characteristics were difficult to reproduce. Experiments reported in the literature have shown that ammonia-nitrogen mixtures will also support AP combustion at low pressures but at a reduced burning rate. A supply of ammonia has been obtained for investigation of the surface burning characteristics using ammonia-nitrogen mixtures.

III. Plans for Future Research

A. Temperature Profile Study

1. Propellant Preparation
    a) A polysulfide-ammonium perchlorate propellant which has given satisfactory burning characteristics in other combustion studies will be tested at JPL by the end of March.
    b) The choice of the propellant formulation to be utilized in the experiment will be made by 1 May.
    c) A series of films of the propellant samples with salted sheets will be completed by 1 April.
2. Servo-controlled Propellant Feedshaft
    a) The new servo-controlled feedshaft will be checked out by 1 May.
3. Temperature Measurements
    a) Measurements of the temperature profile above the burning surface of a strand of propellant will begin on 1 June.

B. Surface Temperature Study

1. Burning Characteristics Study

Continued ignition tests will be performed to determine conditions for obtaining reproducible surface burning characteristics which will permit satisfactory operation of the servo feed system. The following propellant combinations will be investigated:

a) AP strands containing 10% paraformaldehyde in an ammonia-nitrogen mixture at atmospheric pressure.

b) AP strands containing 10% paraformaldehyde in either hydrogen or ammonia and nitrogen mixtures at elevated pressures.

c) Pure ammonium perchlorate in nitrogen atmosphere at pressures above the low pressure combustion limit (approximately 300 psi).

2. Infrared Emission Measurements

Infrared emission measurements from both the propellant surface and flame profile will be made over the range of pressures in which satisfactory burning characteristics are found. It is planned to perform measurements for the following conditions.

a) AP plus 10% paraformaldehyde in gaseous fuel-nitrogen atmosphere at 15, 50, 100, 200, and 300 psia.

b) Pure ammonium perchlorate in nitrogen atmosphere at 300, 500, 800 psia.

(Research Assistants working on this task are as follows: Ronald L. Derr and Nolan E. James.)

Task 3. ATTENUATION OF TRANSVERSE COMBUSTION PRESSURE OSCILLATIONS

I. Introduction

The purpose of this study is to examine the effects of injector-face baffles on the transverse modes of combustion pressure oscillation in rocket combustion chambers of low length/diameter ratio. The analysis is restricted to small-amplitude oscillations, for which the transverse modes are eigenstates satisfying the acoustic wave equation and the boundary conditions imposed by the geometry of the combustion chamber and baffles. The experimental program will employ a small premixed gas-propellant rocket motor with various baffle configurations.

II. Status of Work in Progress

The baffle elements which have been studied analytically consist of radial spokes forming sectors of 30^0, 45^0, 60^0, 90^0, or 180^0, and cylindrical rings with radii 1/3, 1/2, or 2/3 of the chamber radius. The equation which describes the radial pressure profile in the cells formed by these baffle elements (or in the unbaffled chamber) contains a linear combination of Bessel functions whose order depends on the sector angle and the tangential mode number. Radial profiles for Bessel orders from zero through 24 have been computed for the zeroth through fourth radial modes for the three selected ring-baffle radii and for the case where no ring is present. When combined with the appropriate sinusoidal tangential profiles, these radial profiles permit the description of the pressure distribution for modes as complex as fourth radial, fourth tangential in the smallest sector considered (30^0). Higher tangential modes can be described in the larger sectors.

Graphs of representative radial profiles have been prepared, and a computer program has been written which allows direct computer plotting of the two-dimensional pressure distribution in the form of "contour maps." An earlier mapping program, mentioned in the last progress report, required hand plotting of the contour lines. This turned out to be a very tedious process. Contour maps are being prepared for the eight lowest-frequency states in each of the 23 baffle-cell configurations studied and in the unbaffled chamber. In addition, maps of several combination-states, such as the first "spinning" state, are being prepared.

The research motor, test stand, and propellant feed system have been designed. A description of the motor was given in the last progress report.

III. Plans for Future Research

Results of the analytical study described above will be published within the next three months. Fabrication of the research motor and associated equipment is expected to be completed in June. The experimental program, as presently conceived, will investigate eight baffle configurations and will require at least 40 test firings. The motor will be instrumented to allow determination of the approximate oscillatory pressure distribution in the baffle cells.

(Research Assistant working on this task: J. W. Converse)

Task 4. SOLID PROPELLANT IGNITION STUDIES

I. Introduction

The objective of this investigation is characterization of the type of runaway ignition reaction which leads to steady combustion of a solid propellant. The exprimental data will be analyzed for possible correlation with both the homogeneous reaction (gas-phase) ignition model and the heterogeneous reaction (gas phase-solid phase) ignition model.

The experimental technique consists of rapidly exposing a freshly cut surface of a sample of solid propellant to a hot oxidizing gas and measuring the ignition delay (i.e. the time from first exposure to the gas until first light emission from the propellant surface). Gas samples taken near the surface of the sample of solid propellant just prior to ignition will be analyzed by gas chromotography to determine the concentration of fuel vapor near the surface and thus the probability of a gas phase reaction mechanism.

II. Status of Work in Progress

The survey of the literature concerned with the ignition of composite propellants is essentially completed; however, a small effort is continuing in order to keep informed about current work.

Preliminary design of the experimental ignition apparatus is completed. Detailed design and fabrication are continuing. A new test cell to be used for this experiment has been equipped with instrumentation circuits high pressure air and inert gas flow systems, controls for these flow systems, a remote control panel located outside the test cell.

(Research Assistant working on this project is as follows: Stuart D. Kershner)

Task 5. SECONDARY INJECTION OF A GAS INTO A SUPERSONIC STREAM

I. Introduction

As was indicated in the previous progress report the details of the experimental program to be undertaken would be outlined at this time. It should be noted that the objective of this program is to examine certain features of the flow with more detail than in previous work to complement a detailed analytical study. In the following sections an experimental program is outlined for the purpose of clarifying the problem.

II. Proposed Experimental Program

The overall objective of the experimental program is to clarify the mechanisms involved in secondary gas injection so that the phenomena will be susceptible to mathematical analysis. The proposed program is designed to fulfill that objective as nearly as possible within the limitations of available finances, existing research equipment, and the time required to set up and conduct the experiments.

It is proposed that the following experimental program be conducted.

A. Experimental Parameters

1. The experiments will be conducted in a two-dimensional wind tunnel with the primary stagnation pressure held constant at a value which will produce ambient pressure at the nozzle exit when no secondary gas is being injected. Gas will be injected through a rectangular slot extending the width of the primary nozzle. The primary and secondary temperature will not be controllable but will be measured throughout the course of the experiments.

2. Injection Angle. The injection angle will be varied from 0 to 30 degrees measured upstream from a normal to the nozzle axis in increments of 10 degrees. The secondary nozzle will have a 2 degree half angle of convergence for all angles of injection.

3. Injection Pressures. The secondary stagnation pressure will be varied from 40 to 120 percent of the primary stream stagnation pressure in increments of 20 psi. This will insure sonic flow for all pressures. No attempt will be made to investigate secondary flows which are subsonic at the injection point.

4. SEcondary Slot Areas. The secondary slot area will be incremented through 1/2, 1, 2, and 4 percent of the primary nozzle throat. Larger areas force the resulting shock to interest the opposite wall.

5. Primary Stream Mach No. at the Point of Injection. The proposed position of injection for the Mach 2.0 studies is such that the freestream Mach No. at the point of injection is 1.90. It is proposed that the studies be repeated in a Mach 2.75 nozzle (to be discussed later) in which the freestream Mach No. at the point of injection will be approximately 2.60.

6. Secondary Gases. A parameter influencing the magnitude of the side force is the molecular weight of the secondary gas. A minimum of two gases with molecular weights substantially different from air will be employed as secondary injectants. Preliminary studies indicate that Helium and Argon would be suitable gases.

7. Concentration Measurements. To fully understand the mechanism of injection into a supersonic stream a knowledge of the phenomenon of turning and mixing of the secondary stream with the primary stream is necessary. It is proposed that concentration measurements be made to determine the extent of mixing and turning of the two streams with the aid of an absorption photometer to be discussed in Section III.8.

B. Instrumentation and Data Collection

1. The number of static wall pressure taps in the primary nozzle will be increased over the previous experiments. Taps will be located at 0.10 inch intervals for a distance of 2.5 inches upstream of the point of injection and at the same interval for a distance of 1.0 inch downstream of the injection port. The interval will be increased to 0.25 inch to the exit of the nozzle. Taps on the opposite nozzle wall will be placed at intervals of 0.25 inches starting at the geometrical throat and proceeding to the exit of the nozzle.

2. Sparkand continuous arc shadowgraphs will be taken throughout the experiments. It is hoped that the spark shadowgraphs, because they reduce the effective exposure time to 1/1000 of that for continuous arc photographs, will reveal features not discernable when using the continuous arc method.

3. Primary and secondary stagnation pressures and temperatures will be recorded, the pressures photographed and the temperatures recorded on a Brown recorder.

4. Concentration measurements downstream of the point of injection will be made with the aid of the absorption photometer.

III. Outline of the Experimental Program

The experimental program as proposed involves the following major tasks.

1. Relocation of the blowdown wind tunnel in a more suitable test cell.

2. Instrumentation of two nozzle blocks as follows:

(a) placing of pressure taps in nozzle walls as outlined in Section II.B.1, and

(b) cutting an injection nozzle at the desired position in the nozzle block such that the angle of injection can be changed by inserting wedges of various angles to produce the desired injection angle.

3. Construction of a compact bank of monometers for measuring pressure at the numerous stations on the nozzle walls. The monometer bank contains 106 monometers each of which is eight feet in length, the entire bank being four feet wide to facilitate photographic recording.

4. Installing and calibrating thermocouples and Brown recorder for temperature measurements.

5. Installing and checking out spark and continuous arc shadowgraph apparatus.

6. Installing flowmeter in secondary system.

7. Providing means of injecting a tracer gas for concentration studies and also for injection of secondary gases other than air.

8. Constructing and testing an absorption photometer for use in concentration studies. The principal involved in these studies is as follows. A trace of gas (call it A) which absorbs light only in a certain frequency range is injected into a gas of different composition. The absorption photometer is then utilized to determine the concentration of gas A in the dissimilar gas. The method implemented in the studies under report here will be to inject a trace of gas in the secondary stream and traverse the test section where the secondary gas is suspected of being with several beams of light which would then pass through a narrow band filter. The beams would then be directed to an equal number of photomultiplier tubes, the output of which would be recorded on a multi-channel analog tape recorder. The tape would then be fed into a

digitizing computer and the digitized results would be reduced with the aid of an IBM 7094 computer. The results will, of course, be concentrations of the absorbing gas and, assuming a homogeneous mixture of this gas and air in the secondary stream, therefore the concentration (or location of the secondary stream in the primary nozzle). The aforementioned procedure of obtaining data is proposed under the assumption that use may be made of the digitizing computer of the high pressure test facilities and the analog recorder being used in the combustion instability studies or the recorder in the high pressure facilities. Since no absorption photometers of the type needed are commercially made, this apparatus will be made in house.

9. Writing a computer program to analyze the flow in a two-dimensional nozzle with no injection.

10. Modifying nozzle for M = 2.75 flow. It is proposed that this be done by merely reorienting the nozzle blocks used in the Mach 2.0 experiments. This will necessitate new plexiglass sidewalls and steel supports. The injection angles measured with respect to the nozzle wall will remain unchanged, but the nozzle wall will have a different inclination to the nozzle axis. In addition, because of the much higher stagnation pressure required to operate the nozzle correctly (ambinet pressure equal to exit pressure) wall pressures will be out of the range of the monometers at several points in the flow. Therefore, it is proposed that an air powered ejector be fabricated which will lower the back pressure to a point where the primary stagnation pressure may be kept the same as that for the Mach 2.0 nozzle. This will necessitate pulling a 10 psi vacuum at the exit plane of the nozzle. The main objection is the use of additonal pressurized air which is at a premium. It isthought that

the modifications to the primary nozzle to produce M=2.75 flow can be such that the primary flow rate may be reduced and the total flow rate of air primary flow and ejector be held to approximately the same values as for the M=2 experiments.

IV. Status of Work in Progress

At the present time the fabrication is nearly completed and it is expected that actual experimental runs will be initiated by 1 March 1966.

V. Analysis

The data resulting from the experimental program will be correlated and analyzed to determine the relative importance of the various parameters involved in the problem. In particular, an accurate means of predicting the separation point of the turbulent boundary layer will be sought. There are several semi-empirical formulations in existence concerning this phenomenon at the present time; however, none has been applied to such a strong adverse pressure gradient as is present with secondary injection.

Another region of interest is the mixing zone between the primary and secondary streams and knowledge in this area is important in the overall problem. Therefore, with the aid of the concentration measurements an analysis will be made of the turbulent mixing phenomena.

It is felt that the analysis of the secondary injection results and the formulation of a good mathematical model of the secondary injection phenomena is an essential part of the program. It is imperative then that the analysis be initiated at the earliest possible time during the experimental program, i.e. after a sufficient amount of data has been acquired.

(Research Assistant working on this project: Richard D. Guhse)